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Role of Atmospheric Bioaerosols in Atmospheric Corrosion: Short Review

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Abstract. When describing atmospheric corrosion, general terms (air pollution) and conditions (meteorological parameters) are considered. The acceptable corrosion rates that are calculated are generic in nature and cannot be relied upon when estimating the atmospheric corrosion over a geographical region. In this paper, the review of atmospheric bioaerosols was carried-out to enlighten professionals on the need to disintegrate the constituents of air pollutants into aerosols and bioaerosols. This would make it easy for scientists to adequately estimate corrosion rates during airborne pandemic areas. This would certainly lead to the development of ISO standards for this branch of atmospheric corrosion. The success of this research would not be applicable to atmospheric corrosion but in monitoring airborne diseases.

1. Introduction

Bioaerosols are biological airborne particles that are suspended in the atmosphere. That suggests they either begin from a living or dead animal, residue from the plant, sewage, toilet, hospitals, etc. Indoor bioaerosols can be controlled to an extent while the outdoor bioaerosols act like atmospheric aerosols and they are very hard to control (Figure 1). It is believed that atmospheric bioaerosols influence the climate system just like the atmospheric aerosols [1,2]. Bioaerosols in dust were found to carry pathogenic or non-pathogenic live or dead bacteria and fungi, viruses, high molecular weight (HMW) allergens, bacterial endotoxins, mycotoxins, peptidoglycans, $\beta(1\rightarrow3)$ -glucans, pollen, plant fibers [3]. The outdoor bioaerosols are sometimes referred to as atmospheric bioaerosols. Unlike the atmospheric aerosols, they have a living organism or disease that dies at high temperatures. Like atmospheric aerosols, they have basic abilities to disperse and deposit on the whatsoever surfaces. If it deposits on life forms such as humans, it may be harmful or non-harmful depending on the constituents of the bioaerosols.

The indoor bioaerosols are more dangerous because of their enclosure; hence, more persons are likely to inhale it in a closed setting. For example, measles and tuberculosis outbreak in clinics or hospitals or health centers are motivated bioaerosols containing infectious microorganisms [4]. In the industry, soil saprophytic fungi such as *Coccidioides immitis* can be aerosolized during occupational disturbance activities such as building, mining, geophysical survey, etc., and, if inhaled, can result in acute pulmonary infection [5].



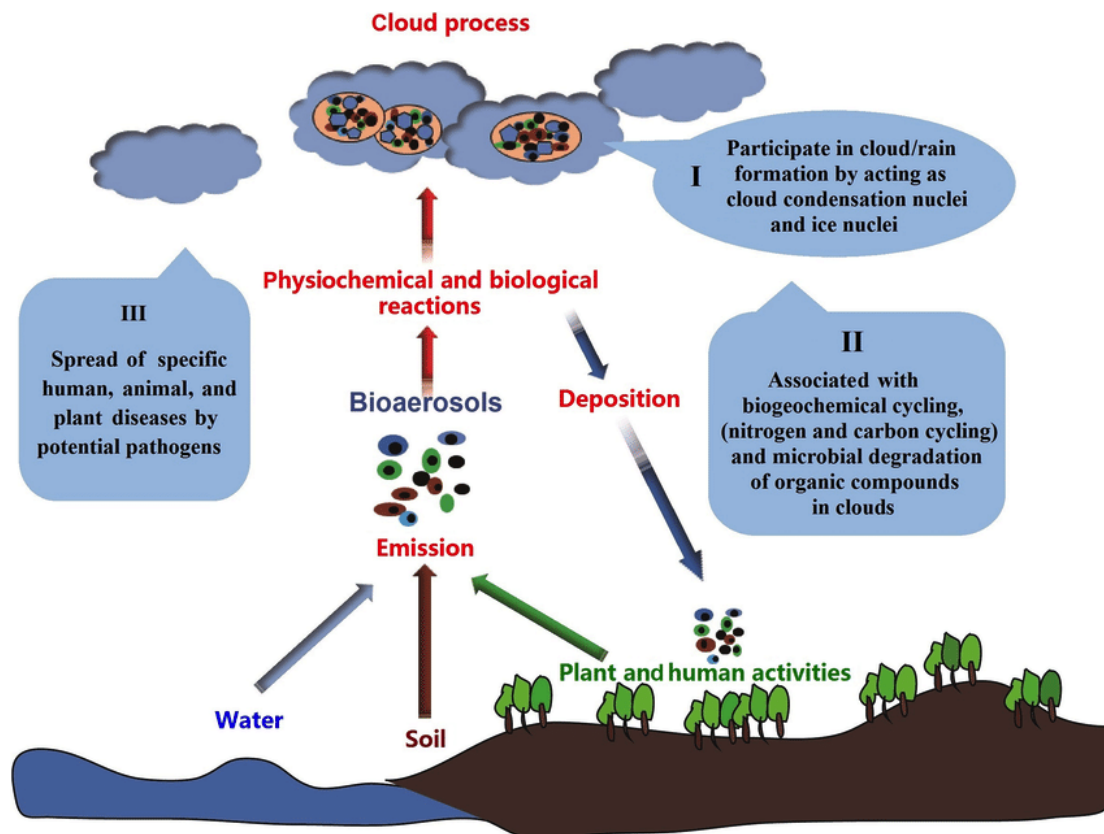


Figure 1. Participation of bioaerosols to the climate system [1]

When bioaerosols' deposits on the metallic surface, surface corrosion of the metal begins depending on the concentration of the microorganism and the moisture content of the bioaerosols. Corrosion is the debilitating of a metal due to chemical reactions within itself and its immediate environment. There are wide scopes of factors that can turn out to be potentially the most significant factor during corrosion. Plainly, the most broadly perceived sort of corrosion is the course of action of iron oxide or rust, outwardly of metals having the properties of iron when there is a reaction with oxygen. Factors causing corrosion are surface heating leading to a grouping of stresses; the high temperature on the surface of the metal; surface interaction with gases, surface interaction with moisture, surface interaction with bioaerosols or aerosols; the property nature of the metal used: the nature of the metal used may cause corrosion if it has low quality; surface properties of the film; structural characteristic of metal, etc.

Atmospheric corrosion of metals is an electrochemical process, which is the sum of individual processes that take place when an electrolyte layer forms on the metal through the formation of thin moisture film or an aqueous film of hundreds of microns in thickness, which helps the metal to corrode in a cathodic process (i.e., reduction of oxygen from the air). Atmospheric corrosion initiated by bioaerosols has a resemblance to microbial initiated corrosion. In this case, there two types of corrosion that are prevalent in bioaerosols-initiated atmospheric corrosion i.e., anaerobic and aerobic corrosion. Sulfate-reducing bacteria (SRB) are a typical example of anaerobic corrosion while sulfur-oxidizing bacteria (SOB) are a typical example of aerobic corrosion. SOB (e.g. thiobacillus) can create an environment of up to 10% sulphuric acid, thereby encouraging rapid corrosion. In this paper, the atmospheric bioaerosols corrosion was reviewed with an emphasis on corrosion mode and bioaerosols control.

2. Bioaerosols influence on metallic corrosion

Bioaerosols contain microorganisms that can isolated rust nuclei on metallic (e.g. steel, iron, etc.) surfaces that can retain moisture film for a long time [6] to form a pit due to a differential aeration cell

mechanism [7]. Bioaerosols that are dominated by bacteria can be either aerobic or anaerobic. With the help of the moisture film or aqueous film, it controls its immediate environment to generate corrosive waste products. For example, aerobic bacteria type of bioaerosols is expected to use the moisture film that has been formed on the surface of the metal to oxidize sulphur to form sulphuric acid that would remove the metallic coating.



This reaction could also form when the bioaerosols oxidize chlorine to form hydrochloric acid. The chemical formula of the bacterial type of bioaerosols gives a better understanding of the dynamics of the chemical reaction when it infests a metallic surface. For example, the magnetotactic bacterial cell (*M. gryphiswaldense*) that is shown in Figure 2, was reported to have a chemical formula of $\text{CH}(2.06)\text{O}(0.13)\text{N}(0.28)\text{Fe}(1.74 \times 10^{-3})$ in its cell wall [8].

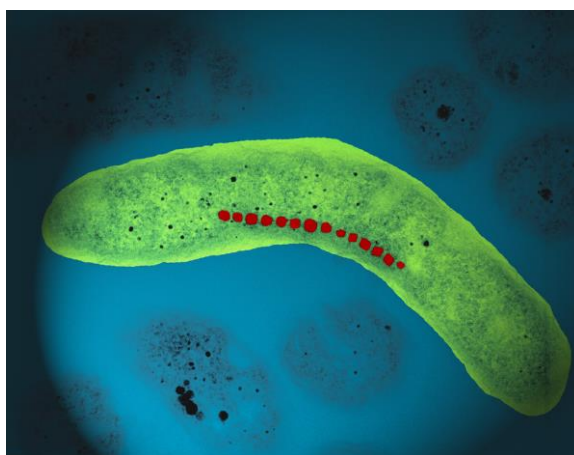


Figure 2. Typical *M. gryphiswaldense* [9]

The hydrogen atom in the anaerobic bacterial may react to reduce sulphates to sulphite or can even form Iron sulphate salt that can enhance a higher rate of corrosion. In other words, two or more reactions can be initiated by the bioaerosols on the surface of the metal or steel. This result makes atmospheric bioaerosols more active in enhancing atmospheric corrosion than the conventional atmospheric aerosols. This cyclic behaviour promotes severe corrosion conditions that can cause damage to unprotected steel exposed to the atmosphere. A typical example is bioaerosols-fungi corrosion illustrated in Figure 3 below. When the fungi type of bioaerosols is deposited on the surface of the steel rod, the cell wall that contains mainly oxygen, hydrogen, nitrogen, and carbon; transfer its dissolved oxygen to the metal surface. The aqueous medium that is created by the microorganisms has the potential to increase or decrease oxygen transport to the surface. The size of the aqueous medium depends on the number of bioaerosols deposited on the metallic surface. The size of the aqueous medium is the main difference between broad and localized corrosion in atmospheric corrosion initiated by bioaerosols and microbial corrosion, respectively. In like manner, the similarity between atmospheric corrosion initiated by bioaerosols and microbial induced corrosion is the formation of discrete colonies when it is deposited on the surface metal. In other words, the aqueous medium is not a continuous film but discrete colonies. That is the main reason atmospheric corrosion initiated by bioaerosols has several corrosion pits as shown in Figure 3. Within the discrete colonies, the microorganism produces sticky extracellular polymers that tend to attract and aggregate other biological and non-biological (metals and chloride, for example) species to the colonization sites. Crevices are formed as shown in Figure 3. Also, there is the formation of oxygen and ion concentration cells that further enhance corrosion.

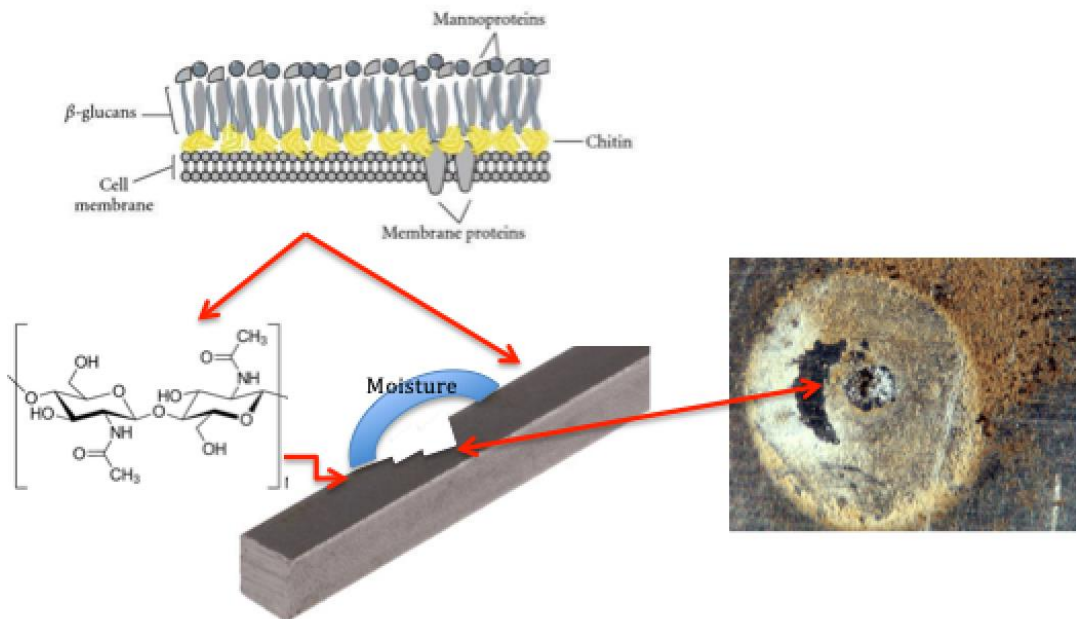


Figure 3. Activity of atmospheric corrosion initiated by bioaerosols

One of the hallmarks of atmospheric bioaerosols corrosion is the nature of corrosion i.e. pitting, dealloying, enhanced erosion-corrosion, enhanced galvanic corrosion, stress corrosion cracking, and hydrogen embrittlement. For example, the difference between atmospheric bioaerosols corrosion and atmospheric aerosol corrosion is illustrated in Figure 4. In other words, during the estimation of atmospheric corrosion, there is the need to distinguish acceptable corrosion rates of atmospheric aerosols and bioaerosols because not all facts defining the corrosion system are considered. It means the acceptable corrosion rates for multiples of corrosion rate at background pollution needs to be reviewed. The formula for acceptable corrosion rates is given as

$$k_a = nk_b$$

k_a is the acceptable corrosion rate, k_b is the corrosion rate at background pollution levels, n is the pollution level which varies with respect to metals [10].

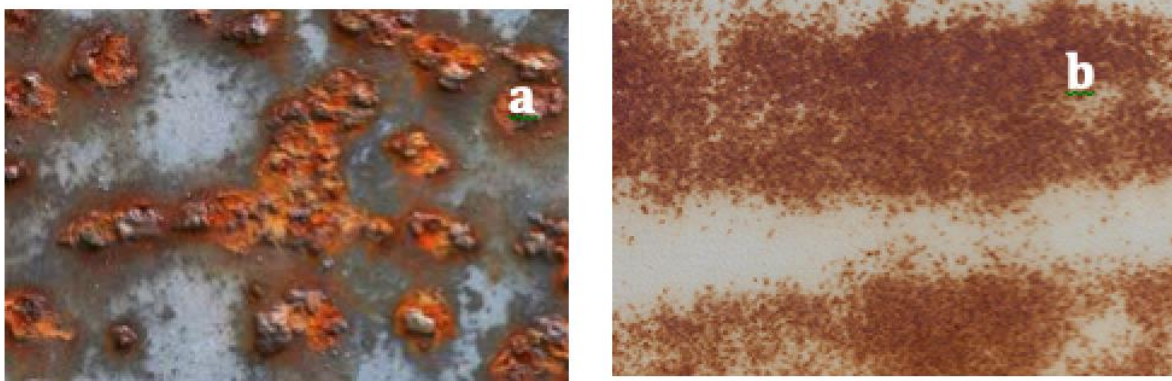


Figure 4. Atmospheric corrosion (a) bioaerosols induced (b) aerosols induced

Based on the new ideas on atmospheric bioaerosols corrosion, it is suggested that the acceptable corrosion rate over a geographical region be calculated using

$$k_a = nk_p + mk_m + \delta$$

Where k_p is the corrosion rate at background pollution levels for non-biological pollutants, k_m is the corrosion rate at background pollution levels for biological pollutants, n and m are the pollution level for non-biological and biological pollutants, δ is the unknown factor which should vary i.e. 2%-6%.

3. Preventing bioaerosols activities on corrosive metals

Corrosion occurs mainly in ferrous or non-ferrous, single crystal or nano-crystalline, cast or wrought, and structural or functional alloys. In the context of this study, the corrosion is strictly related to metallic surfaces. Controlling bioaerosols induced atmospheric corrosion (BIAC) is very important to reduce the cost of maintenance, logistics, and new purchases. Based on the above, this section provides ways of controlling BIAC, which includes physical-mechanical treatment (pigging, ultrasound); electrochemical (cathodic protection); sacrificial coatings; biological (microorganism against another); protective coatings (wrappings, temporary protective materials, paint films, surface coatings of metals, polymers or vitreous enamels, conversion coatings); modification of corrosive environment; chemical treatment with biocides (oxidizing, non-oxidizing, chelate former, electrophiles and membrane-active); use of inhibitors; and cleaning and protection from dust.

Out of the atmospheric corrosion preventive techniques mentioned above. The surface coating technology is very popular. Abrasive-filled alloys coating is used to prevent corrosion, oxidation and wear; Aluminide, silicon-aluminide and cobalt-based MCrAlY alloys coatings are used to protect against hot corrosion; Co-Cr alloys coating is used to improve corrosion and galling resistance; slurries coating is used to protect metals from galvanic corrosion up to 1000 °F / 538 °C; and zinc-aluminum is used as an environmental barrier to mitigate corrosion with cathodic protection. However, there had been known challenges in the coating technique. Radhakrishnan et al. [11] reported that organic coatings may have excellent adhesion, flexibility, and hardness but it exhibits poor tolerance to heat and light, resulting in a pronounced tendency to fade. Poxypolyester powder coating is a hybrid of epoxy and polyester powder coating that has improved resistance to fading and improved weather resistance [12]. However, its shortcomings include: hard to achieve thin coating layers; will break down if exposed to UV rays; color change difficulties; start up costs are high; difficult to touch up; part has to be grounded in order to powder coat; less control over the speed and amount of powder coating applied; and requires baking [13]. Tait [14] reported that the roughness of the metallic surface could lead to numerous internal microscopic defects in the coatings. The defects created allow liquids to absorb into and accumulate in the bulk coating to degrade coating properties and cause the metal under the coating to corrode.

Thermal spray processes include flame spraying with a powder or wire, electric arc wire spraying, plasma spraying, spray and fuse, HVOF spraying, and detonation-gun [15]. The advantages of thermal spray coatings are the following: makes use of a vast array of different materials and substrates, reduces the cost of maintenance. However, the disadvantages are that it creates pores and voids. Pores and voids are microscopic and difficult to observe. Other coating technique includes physical vapor deposition (PVD), post-heat treatment, and slurry coating. However, the point of interest is the monitoring of atmospheric bioaerosols to determine the best coating to prevent BIAC. Polymerase chain reaction (PCR) is used in the industry to monitor bioaerosol monitoring. Bioaerosol monitoring may be appropriate during workplace health and exposure assessments, epidemiological investigations, research studies, or in situations deemed appropriate by an occupational physician or immunologist. Another technique for determining bioaerosols is the aerodynamic diameter technique to determine particulate dynamics. It is used in aerosol science because particles with the same aerodynamic diameter tend to move and be collected in the same ways.

The easiest way to monitor atmospheric bioaerosols is by using laboratory techniques. Liu et al. [16] monitored bioaerosols deposits on the rooftop of a five-story building (about 15 m AGL) at the Hebei Polytechnic University (HBPU) campus in central Huangshi. Then the bioaerosols were characterized using a fluorescence microscope after staining with 4',6-diamidino-2-phenylindole dihydrochloride (DAPI). Hui [17] proposed a lidar configuration that can be used to detect atmospheric bioaerosols (Figure 5). The lidar configuration laser emitting sub-system, receiving sub-system, and data acquisition sub-system. This innovation is termed the hot spot in the field of photochemistry, biochemistry, etc., which works on the principle of scattering, fluorescence, and polarization. Bieber et

al. [18] reported bioaerosols monitoring using drone-based aerosol particles sampling impinger/impactor (DAPSI) system for field studies. This technique was used to investigate sources and near-surface transport of bioaerosols, i.e., particulate matter concentrations (PM₁₀ & PM_{2.5}), temperature, relative humidity, and air pressure at about 0.5 Hz. This technique was supported by the use of a fluorescence microscope to detect bioaerosols. Laser- (or light)- induced fluorescence (LIF) has been suggested to be important in real-time bioaerosols equipment. The equipment makes use of monochromatic light (continuous or pulsed) to investigate the fluorescent properties of individual particles flowing in air through the instrument [19-20]. However, it is still unclear if the application of multiple excitation wavelengths to improve discrimination and reduce false positives can distinctly determine bioaerosols.

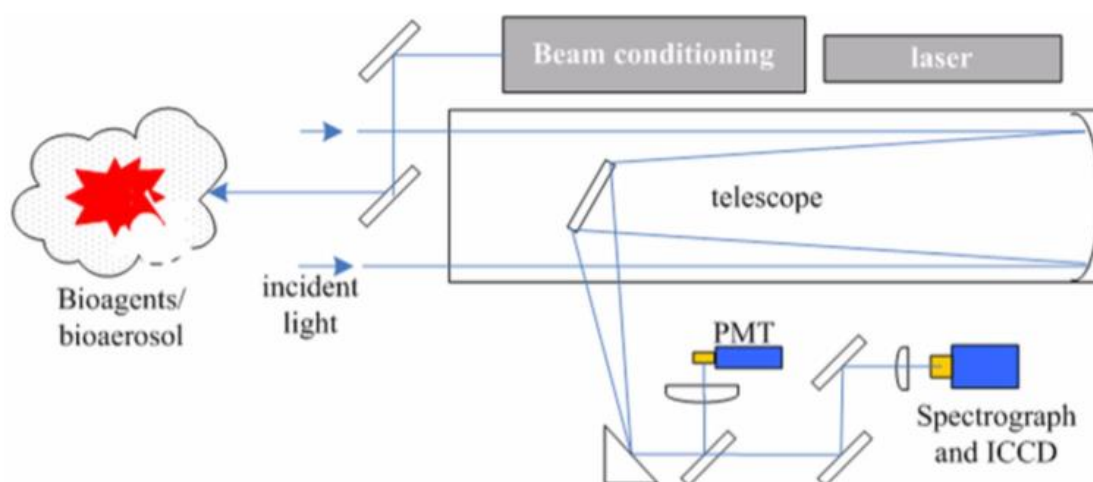


Figure 5. Sketch of bioagent/bioaerosol sensing lidar [16]

From literature, no remote sensing technique has proven to distinctively detect atmospheric bioaerosols. It is therefore expedient that researchers concentrate efforts on atmospheric bioaerosols monitoring. The success of this research would not be applicable to atmospheric corrosion but in monitoring airborne diseases.

4. Conclusion

This review has discovered that the influence of atmospheric bioaerosols is significant in the study of atmospheric corrosion. Hence, there is a need for new ISO standards to guide operators, professionals, and scientists. In light of the above, a new acceptable corrosion rate was suggested for professionals in the field of corrosion. Also, the monitoring of atmospheric bioaerosols is still lagging behind as most remote monitoring devices are still dependent on laboratory characterization for the detection of bioaerosols. The success of this research would not be applicable to atmospheric corrosion but in monitoring airborne diseases.

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